Exploring the Structure of the Solar Wind

Introduction
In this section we will look at the solar wind structure using results from the "Enlil" model (Enlil is the Sumarian God of the Wind, http://ccmc.gsfc.nasa.gov/models/modelinfo.php?model=ENLIL). We will look at results for the same Carrington Rotations that we looked at previously depicting conditions near solar minimum (CR 2080) and solar maximum (CR 1960). The simulations you will look at follow the solar wind evolution from approximately 0.15 AU (inside the orbit of Mercury) to 10 AU (just outside the orbit of Saturn).
When you finish you should be able to:
- **interpret visualizations of solar wind model results**
- **describe the global structure of the solar wind at different phases in the solar cycle**
- **relate the plasma parameters and magnetic field structures in the solar wind**

Variation in the Plasma Parameters
- In SWX, use the "File" menu to navigate to "Solar Wind" directory and open the file "min2080.cdf". This is the solar minimum case.
- Use the "+" button to add a cut plane window. A new tab will appear. Click on the "tool" icon for that tab adjust the parameters to add a constant "R" ("Component" menu) surface at the inner boundary (R = 0.144 AU) ("Constant Value") painted with the radial component of the solar wind velocity (Vr) ("Variable").
- A window will appear showing the inner boundary of the simulation. This inner boundary is driven by input from a solar corona model such as MAS or WSA.
    - **What can you say about the organization of the solar wind on this inner boundary? Make note of the color scale.**
    - **Use the "tab tool" to change "Vr" to "Vlat" and "Vlon" to get the theta and phi components of the velicity. What do you notice about the structure and scale?**
    - **Use the "tab tool" to adjust the distance of the radial cut from the sun. Verify that your observations are consistent with at different distances from the Sun.**
    - **Does the overall solar wind speed change much with distance from the Sun?**
- Use the "+" button to add another cut plane in the "Phi" direction.
    - **Is this cut plane consistent with what you have seen already?**

- Reset the radial cut plane to the inner boundary paint it with density ("N").
    - **What can you say about the organization of the solar wind on this inner boundary? How does this correlate with the velocity structure you saw before?**

- Use the "+" button to add an equatorial cut plane ("Z" = 0) and paint that with density.

- To view both cuts at the same time, use the "3D" view from the view menu. Be sure to rotate the view and explore the image.
  - **How does the density change with distance from the sun? Why does it change this way?**
  - **In the original window, mouse over points on the Z=0 cut plane and explore the values. Choose values at 0.25, 0.5 and 1 AU. As the distance from the Sun doubles, what happens to the value of the density?**
- Change the variable painted to "N*r^2" which is the density multiplied by the square of the distance from the Sun.
  - **Discuss the structure you see now with your group. Why does plotting density this way help bring out the structure?**

Magnetic Field and the Solar Wind Flow

The magnetic field structure and the plasma velocity often cause some confusion among students. This section will have you explore both.
  - **In your groups, discuss the direction of the flow velocity of the plasma.**

- At the top of the main SWX window is a drop down menu labeled "Streamlines". It should be set to "B" so that it draws field lines. In the visualization window on the equatorial cut ("Z" cut plane) click on some points. These will be seed points for field lines that appear. You should also see these in the "3D" window.
- Choose some points at the inner boundary image on the "Constant R" tab.
  - **With your group, describe the global structure of the magnetic field. Is it the same in the equatorial plane and at higher latitudes?**
  - **What direction do you expect the plasma to flow in?**
- Choose "View -> Seed Point" and clear all the seed points. In the main window select "V" in the "Streamline" menu. Click on points in the equatorial plane. These now show flow lines of the plasma.
  - **Are these flow lines what you expected? Discuss this with your group.**

Solar Wind at Solar Maximum (Homework)

- In SWX, use the "File" menu to navigate to "Solar" directory and open the file "max1960.cdf". This is the solar maximum case. Follow the directions above and compare the results you get to the solar minimum case.
  - **What generalizations can you make about the structure and variation of the solar wind parameters at solar maximum?**
  - **How do these generalizations compare to those made at solar minimum?**

Visualizing the Solar Wind

We can look at data and simulation results for the solar wind in the iSWA system. Open the following link:

http://iswa.ccmc.gsfc.nasa.gov:8080/IswaSystemWebApp/index.jsp?
i_1=48&l_1=14&t_1=681&w_1=927&h_1=729&s_1=0_0_10_3&i_2=177&l_2=650&t_2=
251&w_2=697&h_2=435&s_2=0_0_10_3&i_3=173&l_3=3&t_3=255&w_3=640&h_3=41
0&s_3=0_0_10_3&i_4=67&l_4=670&t_4=677&w_4=696&h_4=738&s_4=2012-05-19%2
022:31:38.0_0_10_3

Four panels appear.
- The top two are output from the Enlil model that shows cut planes similar to the three we explored above. One panel shows plasma velocity and the other shows normalized density. These cut planes are all defined by the relative position of the Earth and the Sun. The first cut plane is the ecliptic plane, the second is the meridial cut for the Earth, and the last is a radial surface at 1 AU.
- The left panel on the bottom is a stack plot of solar wind parameters from the ACE and STERO B space craft. We will only be concerned with the ACE space craft (http://www.srl.caltech.edu/ACE/) which is at Lagrange point "1" just "up stream" from Earth in the solar wind.
- The final plot shows the Enlil prediction of the solar wind parameters at L1. Carefully examine the parameters plotted and compare them to the order of the ACE data. Also carefully examine the time axis.

- Use the "Global Date" menu to choose a date in April of 2010. This is still near solar minimum (see http://www.swpc.noaa.gov/SolarCycle/).
    - **Is the global structure of the solar wind consistent with what you know about solar minimum from above?**
    - **Compare the ACE data to the Enlil results. What details does the Enlil model capture? What does it miss? (You may have to use the arrows at the bottom of the Enlil signet to adjust the dates visible.**

The CME that Killed Galaxy 15

Galaxy 15 is an American telecommunications satellite. It was originally positioned in geostationary orbit at a longitude of 133° West, from where it was used to provide communication services to North America. On April 5th 2010 (~ 9:48UT), Intelsat lost control of the satellite, and it began to drift away from its orbital slot, with the potential to cause disruption to other satellites in its path. At the time of failure the Galaxy 15 was located at the night side. One of the possible reasons for Galaxy 15 failure is surface charging that can be cause by increase flux in energy channel ~22Kev

We can view the CME that initially caused this event using this link.

http://iswa.ccmc.gsfc.nasa.gov:8080/IswaSystemWebApp/index.jsp?
i_1=205&l_1=986&t_1=273&w_1=500&h_1=500&s_1=2010-04-03%2010:54:00.0_0_10
_3&i_2=207&l_2=12&t_2=273&w_2=500&h_2=500&s_2=2010-04-03%2010:54:00.0_0
_10_3&i_3=14&l_3=494&t_3=275&w_3=500&h_3=500&s_3=2010-04-03%2010:55:00.
0_0_10_3&i_4=211&l_4=13&t_4=769&w_4=910&h_4=258&s_4=0&i_5=213&l_5=13&t_
5=1017&w_5=910&h_5=258&s_5=0&i_6=273&l_6=817&t_6=773&w_6=640&h_6=410&
s_6=2010-04-03%2017:00:00.0_0_10_3

Set the global date to 2010-04-03 11:00 UT.

- The top three panels are coronagraphs images from three different spacecraft. Coronagraph images are made using a white light camera with a disk placed in the field of view to block out the Sun. With the Sun blocked out, the light scattered off the tenuous plasma can be viewed showing any structure present. The central cygnet is a coronagraph from the SOHO spacecraft (http://sohowww.nascom.nasa.gov/) which monitors the Sun from the L1 point just upstream of Earth. The other two are from the STEREO spacecraft (http://stereo-ssc.nascom.nasa.gov/) orbiting ahead and behind the Earth. The SOHO spacecraft provides a head on view of the Sun while the two STEREO images are off to the side. For the date in questions, you can see the position of the STEREO spacecraft below.
- Two of the panels below show a series of images from each of the STEREO spacecraft. This allows for easy tracking of the CME from one image to the next.
- The final panel shows the Enlil-Cone model run for this event.
  - **Consider the scale of the Enlil graphic. What are the size of the coronagraph images relative to the Enlil depiction?**
  - **What do you notice about the global structure of the CME in the coronagraph images? In the Enlil model?**
  - **Does the CME interact with the background Solar Wind? What is your evidence?**

For a final look at this event, we can compare the solar wind data to the simulation results.

http://iswa.ccmc.gsfc.nasa.gov:8080/IswaSystemWebApp/index.jsp?
i_1=261&l_1=4&t_1=299&w_1=771&h_1=540&s_1=2010-04-03%2018:02:02.0_0_10_3
&i_2=48&l_2=777&t_2=301&w_2=640&h_2=480&s_2=2010-04-07%2018:10:02.0_0_1
0_3&i_3=297&l_3=290&t_3=842&w_3=940&h_3=300&s_3=2000-04-04%2018:03:00.0
_0_10_3

- **How well does the simulation results mimic the actual observations?**
- **What could explain the differences in the two?**
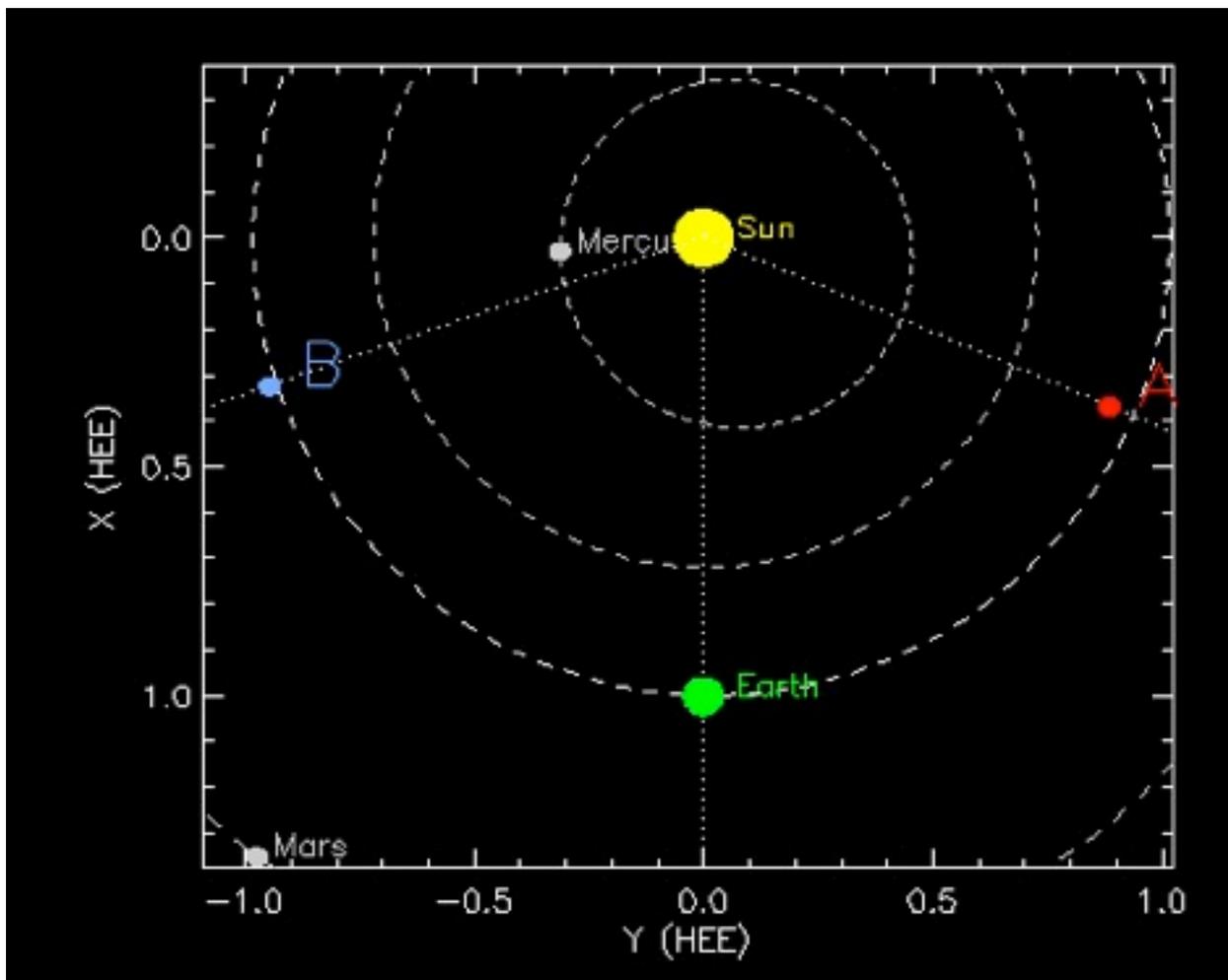
This image was created using the STEREO orbit tool
http://stereo-ssc.nascom.nasa.gov/where/